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Integration of Woody Perennials in Production Systems to Augment Feed Availability in Hot Arid Region: A Review

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Abstract: Livestock is the mainstay of agrarian economy of the hot arid region. However, shortage of fodder and feed is one of the main constraints of animal production in the region. Trees and shrubs are indispensable sources of animal feed in arid region. They can alleviate the feed shortages or even fill up the feed gaps in the winter and especially in the summer period when grassland growth is limited or dormant, due to unfavorable weather conditions. Destruction of natural habitats, over exploitation and increased mechanization in agriculture during the concluding couple of decades resulted in a precipitous fall in the number and diversity of woody perennials in cultivated and other lands. There is an urgent need to conserve and sustainable utilization of fodder tree and shrubs to augment feed availability in hot arid region. In this paper an attempt has been made to review the significance and nutritional quality of tree and shrubs for livestock. The integration of trees and shrubs in agricultural and pasture production systems is explored. The important constraints for their utilization and need for research and development are discussed.

Key words: Alternate land use, tree, shrub, fodder, livestock.

Livestock systems occupy ~30% of the planet's ice - free terrestrial area (Steinfield *et al*., 2006). Livestock plays multiple roles (societal, economic and environmental) in the livelihoods of people in developing countries especially the poor. They contribute about 40% to the agricultural GDP (Anonymous, 2009), employ at least 1.3 billion people globally, and directly support the livelihoods of 600 million poor smallholder farmers (Thornton *et al*., 2006). They contribute 17% to the global food balance and 33% of the protein in human diets (Anonymous, 2008); manure for supplying plant nutrients, provide a safety net in times of need (as liquid assets), and a strategy of diversification for food production (Freeman *et al*., 2007); raise the social status of owners and contribute to gender balance (Waters-Beyer and Letty, 2010). Population increase, urbanization, and increasing income have resulted in a rapid growth in requirement for livestock products, which is likely to extend well into the future (Delgado, 2005). So the sustainable farm animal production is an imperative to nutritional, livelihood and environmental security globally.

The livestock population in India has increased from 292.8 million in 1951 to 536.8 million in 2019 (20th Livestock Census). Livestock is an important sector of Indian economy which grew at a CGAR of 8.15% during 2014-15 to 2019-20 (at constant price), the growth in livestock sector is more than crop sector. The contribution of livestock in total agriculture and allied sector GVA has increased from 24.32% to 29.35% during 2014-15 to 2019-20. Hot arid regions of India cover an area of 31.7 million hectares. Rajasthan constitutes ~61.8% of the entire area of the hot arid region in India. This region is characterized by low and erratic rainfall, high evapotranspiration, extreme temperatures, high wind speed (Rao and Singh, 1998); coarse textured, low nutrient content and poor water retentive soils (Gupta *et al*., 2000), and scanty water resources. The crop production in this area is low, unstable and risky. Livestock is the major components of farming systems and livelihood of farmers in this region (Bhati and Joshi, 2007) and vital for resource poor peasants of arid region to take on their socio-economic need, security and survival (Davendra, 1998). Livestock sustains arid farming systems by virtue of their potential to reduce risk (Mittal and Prasad, 1990; Patel, 1991), alleviate poverty, important providers of nutrients and traction for growing crops

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in smallholder systems and the imparting sustainability of household.

The hot arid region of Rajasthan has about >30 million contributes >40% of total milk, meat and wool production of Rajasthan. The livestock productivity in this region is low, i.e. average milk production for cattle, buffalo and goat is 4.1, 5.6 and 0.9 kg head^{-1} day^{-1}, respectively. The average productivity of wool from sheep is 1.8 kg head^{-1} year^{-1} (Patil *et al*., 2009). Pasture and grazing lands, residential area and wayside grazing lands, crop by-products and residues, fodder crops, non-conventional by-products of Agro-industry processing are major feed resources in arid areas. For the large ruminants, the crop residue constitutes 60-70% of total feed supply (Patil *et al*., 2009). For the small ruminants the rangelands and fodder from trees and shrub is the major source of feed supply.

Most of the livestock, particularly ruminants in pastoral and extensive mixed systems suffer from permanent or seasonal nutritional stresses. Poor nutrition due to lack of adequate and quality feed is a major constraint of livestock production in hot arid region (Venkateswarlu *et al*., 1992; Singh *et al*., 2007, 2009). Venkateswarlu *et al*., (1992) estimated requirement of 28.13 million tons of fodder for the year 2000 on dry matter base. An estimate by Patidar and Saxena (2007) suggested that arid Rajasthan having livestock equivalent to 10.96 ACU requires 39238 thousand tons dry matter per year. Dry roughage and green forage requirement will be 21849 and 41200 thousand tonnes, respectively. Additionally, ~13 million tons of concentrate will be required to feed 23.96 million livestock in arid regions of Rajasthan. Pratap Narain and Kar (2005) estimated that the availability of dry and green forage is 14000 and 8710 thousand tonnes in a normal rainfall year. In event of drought year the availability of dry and green forage estimated to decline to 4390 and 2690 thousand metric tons. These estimates show during the normal rainfall year the dry and green forage are 35.9% and 78.9% deficit. During drought year the respective deficit is 79.9% and 93.5%. The overall shortage of fodder varied from 76% in the western districts to 81% in eastern portions of the area. In this paper, the potential of fodder trees and shrubs as animal feeds is analyzed and discussed and their integration into the production systems is explored.

Role of trees and shrubs as feed resources

Several reviews and studies in various parts of the world have shown that tree and shrub play a very significant role in the nutrition of livestock in arid and the semi-arid lands of the world (Le Houerou, 1980; Otsyina and McKell, 1984; Tothill *et al*., 1989; Atta-Krah, 1990; Lefroy *et al*., 1992; Singh *et al*., 2007, 2009; Rathore *et al*., 2011; Rathore and Singh, 2012). Shankarnarayan (1984) opined that in arid region animals fed more on shrubs and trees than on grass and pasture legumes. The specific advantage associated with the trees and shrubs compared to annuals (grass and legumes) includes: deep root system and can withstand drought often serving as the main source of forage during dry season; some perennials are multipurpose and yield fuel wood, timber, thatching materials, food, etc.; these once established are easier to maintain in association with grasses compared to creeping legumes and they can be grown as a component of two and three tier production systems.

In addition, perennial plants make the best usage of soil and climate in areas with a long dry season (Ben Salem, 1980). Annuals are more vulnerable to climatic fluctuation and year-to-year variation in rainfall and temperature. These plants depend on specific climatic requirement e.g., onset of rain during their formation and development (Ben Salem and Erin, 1982; Ben Salem and Palmberg, 1985). In contrast to annuals, growth of perennial does not depend on rain starting within a few days or weeks on a certain date. Furthermore, most of the perennials growing in arid regions possess physiological and structural features, which assist them to withstand extended period of moisture deficit. Secondly, if variations in climatic conditions adversely affect growth and maturation of these perennials, this does not result in complete failure as once the condition becomes favorable; these plants are likely to resume their full potency. Therefore, trees and shrubs are essential sources of animal feed, particularly in arid climatic areas. This is because they can alleviate the feed shortages or even fill up the feed gaps in the winter and especially in the summer period when

Table 1. Nutritive value of fodder tree leaves of the arid region Unit to be given

Species	CP*	CF	EE	NFE	Ash	Ca	P	DCP	TDN
Ailanthus excelsa	19.87	12.72	3.53	51.81	11.97	2.11	2.11	16.24	63.80
Acacia senegal	10.30	9.70	-	65.70	16.40	6.90	6.90	-	
Azadirachta indica	14.50	23.08	2.31	21.59	8.52	2.39	2.39	8.38	53.28
Prosopis cineraria	13.98	17.80	1.88	43.44	22.90	2.73	2.73	4.49	40.99

*CP: Crude protein, CF: Crude fiber, EE: Ether extract, NFE: Nitrogen free extract, DCP: Digestible crude protein, TDN: Total digestible nutrients. Source: (Jat *et al*., 2011).

grassland growth is limited or dormant, due to unfavorable weather conditions.

Prosopis cineraria (L.) Druce, *Acacia senegal* (L.) Willd., *Cordia gharaf* (Forsk.) Ehrenb. ex Asch., *Salvadora oleoides* Decne. and *S. persica* L. are important fodder tree species of arid region of Rajasthan. The nutrient value of important fodder tree species is represented in Table 1. *P. cineraria* is most important fodder tree species of the area. An average size tree yield ~10 kg leaf fodder. Bohra (1980) reported that the dry matter intake of *P. cineraria* leaf fodder in goats was almost double than those in sheep and that the digestibility coefficients of DM, CP, EE and CF were higher in goats than in sheep. Its leaves either green or dried, when fed along with concentrates is a valuable feed resource for small ruminants. The mixed ration consisted of *P. cineraria* leaves and concentrates @ 20:80 for lambs (Bhatia *et al*., 1976) and @ 50:50 for kids (Parthasarathy, 1986) recorded maximum growth rates of 80 and 100 g, respectively. Mathur *et al*., (2003) reported that pod powder of *Prosopis juliflora* (Swartz) DC. could be used @ 35% concentrate for lactating goats. Mathur *et al*., (2002) identified pod husk of *P. juliflora* and seed cake of *Citrullus colocynthis* (L.) Scharad. in 1:1 ratio as a low cost ration for sheep of the hot arid region.

Studies carried out at ICAR-CSWRI, Avikanagar, Rajasthan suggest that daily meal as 50% *Ailanthus excelsa* Roxb. leaves and 50% wheat straw could form maintenance ration for sheep. The mutton yield of ewes kept on silvi-pastoral system having *A. excelsa* was higher than ewes kept on sole *Cenchrus ciliaris* pasture. An average tree of 5, 10 and >20 year age provides 100, 200 and 400 kg green leaves. The intake and digestibility studies on male weaner broiler lambs with *A. excelsa* and *Ziziphus nummularia* (Burm.f.) Wight & Arn. base ration revealed that digestibility of DM, CP, CF and NFE were higher in *A. excelsa* based ration than *Z. nummularia* based ration (Jat *et al*., 2011).

Shrubs constitute <20% of desert flora, and cover >70% of desert landscapes from Aravalli to the international border of the Indian part of Thar Desert. In arid regions, shrubs are an important source of feed and they assure feed availability in a drought situation (Pratap Narain and Kar, 2005). The significance of shrubs in augmenting feed availability in hot arid region is highlighted by Singh and Rathore (2005) and Rathore *et al*. (2011). The important fodder shrub species of hot arid region of Rajasthan is mentioned in Table 2.

Acacia jacquemontii Benth., *Calligonum polygonoides* L., *Capparis decidua* (Forsk.) Edgew., *Grewia tenax* (Forsk.) Fiori, *Haloxylon salicornicum* (Moq.) Bunge ex Boiss.and *Ziziphus nummularia* are important fodder shrub species of the area. Livestock rearers consider leaves of *Z. nummularia*, fruits of *C. polygonoides*, fruiting twigs of *H. salicornicum* and leaves and pods of *A. jacuqemontii* as good and phylloclade of *C. polygonoides*, green twigs of *C. decidua*, *Heliotropium rariflorum* Stocks, *Indigofera oblongifolia* Forsk. as medium category of fodder (Singh *et al*., 2007).

Nutritive value viz. CP, CF, EE, NFE and ash content of shrub species of hot arid region indicate that the fodder of shrubs has 6-12% crude protein. Hence, shrubs intake by animals will supplement the protein content of total feed intake. The fodder of shrubs is also rich in minerals like iron (35-50 ppm), Mn (10-30 ppm), Cu (8-10 ppm), Zn (35-50 ppm), Ca (0.21-0.53%), Mg (0.041-0.01%) and K (0.5-0.7%) (Shankar *et al*., 1988). Thus, fodder of the shrubs is an important source of protein and minerals for livestock of the hot arid region.

Ziziphus nummularia is a multipurpose shrub species which provide edible fruits, leaves as forage, wood as fuel, for construction and furniture. This species can withstand harsh

Table 2. Important fodder shrub species of hot arid Rajasthan

Species	Browsed by
Acacia jacquemontii Benth.	Camel, goat
Alhagi maurorum Medic.	Camel
Calligonum polygonoides L.	Camel, goat
Capparis decidua (Forsk.) Edgew.	Camel, goat
Clerodendrum phlomidis L.f.	Camel, goat
Grewia tenax (Forsk.) Fiori	Goat, camel
Grewia villosa Willd.	Goat, camel
Haloxylon salicornicum (Moq.) Bunge	Camel, sheep
H. recurvum (Moq.) Bunge ex Boiss.	Camel, goat
Heliotropium rariflorum Stocks	Sheep, goat, camel, cattle
Indigofera oblongfolia Forsk.	Sheep, camel
Lycium barbarum L.	Goat, camel
Maytenuse marginatus (Willd.) Ding Hou	Goat, camel
Mimosa hamata Willd.	Sheep, goat, camel
Salsola baryosma (Roem. & Schult.) Dandy	Camel
Suaeda fruticosa (L.) Forsk.	Goat, camel
Ziziphus nummularia (Burm. f.) Wt.	Goat, sheep, cattle, camel

conditions such as drought, salinity and temperature (Bhandari, 1990; Pareek, 2001). It is an important leaf fodder shrub species of hot arid region, and a vital component of the silvi-pastoral system of arid region (Shankar, 1980). The leaves provide fodder for livestock in the summer months, particularly in the fodder-deficient areas in north-western hot regions of India (Shankar, 1980; Shankar and Kumar, 1981). The shrub is grazed by livestock at tender stage, but when the plant becomes old, wooden and thorny, only camel, sheep and goats can browse on it. During the onset of fruiting in winter the leaves start falling and collected, dried and stored for off-season requirement. Its fodder from the dried leaves (known as 'Pala') is fed to camels, goats, buffaloes and cows. The dried leaves may preferably be given with some form of chaff, bhusa (straw). The branches are cut generally twice in a year i.e. in April and November. It has high leaf fodder production potential (125 kg ha^{-1} of dry leaf) and the combined yield of the leaf fodder and grass to the tune of 1000 kg ha^{-1} was reported from the arid scrub grazing lands with its moderate density (14%) (Kaul and Ganguli, 1963). It could produce fodder to the tune of 170 kg ha^{-1} in alluvial plain receiving annual rainfall between 250-300 mm (Muthana, 1984). Shankar and Kumar (1981) estimated leaf fodder from four habitats, five soil types and four land use systems and found yield from 6.4 kg ha^{-1} to 169.2 kg ha^{-1}. Singh and Saini (2002) reported 11.5% CP, 33.8% CF and 80.6% carbohydrates in its leaf fodder.

Dry phylloclades of *Calligonum polygonoides* locally known as "*lasu*" have good digestibility and is potential top feed species of region (Gaur *et al*., 1982). It is preferred fodder for camel. A well mature plant yields about 1-2 kg dry fodder (Kaul, 1965). Total biomass production is higher on bare dune plantation (29.3±2.2 kg $plant^{-1}$) followed by semi-stabilized dune (16.2±1.0 kg $plant^{-1}$) and flatland plantation (10.6±0.6 kg $plant^{-1}$) (Singh, 2004). Its fodder is fairly nutritive having 4.1% DCP, 54.4% TDN. It is good fodder for camel and fed after mixing with other feed materials such as straw of clusterbean (*Cyamopsis tetragonoloba* (L.) Taub.) and moth bean (*Vigna aconitifolia* (Jacq.) Marechal) (Saxena, 1988). Its fodder is nutritive (Dhir *et al*., 1984; Sharma *et al*., 1984; Bishnoi and Gautam, 1991). Its seeds contain 12.1% CP, 1.9% EE, 29.6% CF, 7.4% ash, 78.62% TCHO, 44.3% ADF, 68.3% NDF, 92.6% OM and 49.0% NFE. Total dry matter intake, digestibility coefficient of EE and NFE, body weight gain were significantly higher in camel fed on combination of *C. tetragnoloba* and *C. polygonoides* (in 30:70 ratio) fodder compared to animals fed on sole *C. tetragonoloba*. Thus its inclusion with *C. tetragonoloba* fodder @ 30% significantly improved the intake and utilization of nutrients and overall performance of camel (Saini *et al*., 2005).

Haloxylon salicornicum belongs to family Chenopodiaceae, is well-known camel fodder of the region (Singh *et al*., 2015). It is an important browsing shrub species of western Rajasthan (Kaul 1986; Shankar, 1988). It along with Sewan (*Lasiurus scindicus* Henr.) and Murath (*Panicum turgidum* Forsk.) grasses forms a very productive grazing land ecosystem (Shankar and Kumar, 1984). Phenology of these two groups of plant appears to complement each other with respect to availability of fodder. Whereas forage from grasses is available during monsoon; the browse from *H. salicornicum* is available during lean period (December-

March). Its fruiting tops contain higher protein (14-19%) and minerals (21-24%) as compared to twigs (Mondal *et al*., 2006). In hot arid region of Rajasthan, farmers harvest its fruiting top during November-December and preserve for further use as fodder. It feds generally after mixed with "*guar phalguti*" (left over threshed material of *C. tetragonoloba* consisting stover and threshed pods) and "*Lasu*" (phylloclade of *C. polygonoides*). It produces seed (with perianth) up to 3.2 kg plant^{-1}. The seed with perianth contains 18.9% CP, 13.89% CF, 1.80% EE, 35.91% ADF, 71.08% NDF and 24.70% ash (Singh *et al*., 2009). The results of studies conducted at ICAR-CAZRI, Jodhpur revealed that its seed could replace the feed concentrate up to 25 and 50% in cattle and goat, respectively. Besides, economic significances as fodder species, the *H. salicornicum* and *C. polygonoides* are very effective in restoration of degraded rangelands in hot arid region (Rathore *et al*., 2015)

Haloxylon recurvum (Moq.) Bunge ex Boiss.is a chenopod succulent halophytic shrub which is browsed by camel and goat (Rathore *et al*., 2012). Its green foliage is rich in CP (13.20%), TCHO (62.9%), CF (20.7%), NDF (58.2%), and ADF (25.2%). It could be fed to goats by mixing with groundnut haulm in 1:3 ratio (Mondal *et al*., 2005). Green foliage of another halophytic shrub *Salsola baryosma* (Roem. ex Schult.) Dandy could be used as alternate feed for goats during drought (Mathur *et al*., 2007). Jakhmola *et al*., (2012) evaluated the effect of incorporating leaves of *Acacia jacquemontii* in Sewan grass (*L. sindicus*) base composite diet on *in vitro* gas production and suggested that *A. jacquemontii* have potential to favourably modulate the rumen fermentation.

The forgoing discussion suggests that trees and shrubs are an important source of feed in hot arid region because of their palatability, good nutritive value and availability in lean period. They constitute a feed reserve for livestock in periods of inter-seasonal or inter-annual drought in arid region.

Integration of fodder trees and shrubs into agricultural systems

Fodder tree and shrubs integration into crop and pasture production systems improve the quality and quantity of fodder leading to improved animal production. Integration of fodder trees and shrubs into existing farming and land use system has been advocated by several workers (Le Houerou, 1980; Torres, 1983; Atta-Krah, 1993; Singh *et al*., 2008; Rathore *et al*., 2011). The success and degree of integration of woody perennials into crop and pasture production system depends on climatic (amount and reliability of rainfall), soil characteristics, compatibility of the associated crops and management of components for sustainability (Otsyina *et al*., 1999). Some of potential alternate land use systems (ALUS) which could integrate fodder tree and shrubs are discussed below:

Silvi-pasture: Silvi-pasture refers to combination of grasses, legumes and trees/ shrub for optimizing land productivity, conserving plants, soil and nutrient to produce forage, fuel wood, timber etc. on sustainable basis. Silvipastoral systems are integral part of traditional agroforestry of hot arid region of Rajasthan. Tewari *et al*. (1999) gave detailed account of structural and production function of traditional agroforestry of this region. They reported that herbage biomass yields of *Acacia senegal*, *A. tortilis* (Forsk.) Hayne, *Ziziphus* spp. and *Prosopis cineraria* based protected silvipastoral systems are 1.2, 1.5, 2.3 and 3.9 Mg ha^{-1}, respectively. Approximately 75% of total area of hot arid region is degraded and not suitable for annual crop production (Dhurvanarayan, 1993). Silvi-pasture system is an ideal alternative for development of such degraded lands (Rai, 2008). Keeping 10-15% of total land holding as fallow for 2-3 years is normal practice among farmers of arid regions. Such areas may be developed as silvi-pasture and then as agroforestry and agri-horti system. *Albizia lebbeck* (L.) Benth., *Tecomella undulata* (Sm.) Seem, *Colophosperumum mopane* (Krik. ex Benth.) Krik ex J. Leonard, *Acacia senegal, Ziziphus nummularia* and *Z. rotundifolia* Lam. are compatible woody species with grasses for silvi-pasture system in arid region. Among pasture legumes *Clitoria ternatea* L. and *Lablab purpureus* (L.) Sweet showed good compatibility with *Lasiurus sindicus* and *Cenchrus ciliaris* L. (Bhati *et al*., 1986).

Shankar (1980) reported that silvi-pasture yielded seven times more forage compared to other land uses in marginal and sub-marginal arid lands. Silvopastoral system consisting of *A. nilotica* + *C. ciliaris* and *A. tortilis* + *C. ciliaris* planted at 3×3 m spacing produced on

an average biomass yield of 2.5 and 2.7 t ha^{-1} year^{-1}, respectively. Studies on the production potential of pasture alone (*C. ciliaris*), fodder trees alone (*Hardwickia binata* + *Colopospermum mopane*) and silvopastoral system (*C. ciliaris* + *H. binata* + *C. mopane*) were compared at ICAR-CAZRI, Jodhpur for nine years. Results indicate that silvopastoral system was better for higher average forage production and livestock maintenance followed by pure pasture and pure trees block (Harsh et. al., 1992). Sharma *et al*., (1994) reported that replacement of natural grass cover with *C. ciliaris* and introduction of top feed species (*Z. nummularia* and *Grewia tenax*) increased production by 2-3 times in arid lands. Bhati (1997) reported that grazing of mixed flock of sheep and goat on silvi-pasture consisted of *Z. nummularia* with *C. ciliiris* (strips plantation 1:2 ratio) had higher live weight and wool yield compared to that grazed on sole pasture. Arya (2006) assessed yield of *Cenchrus ciliaris* in association with three tree species (*Ziziphus marutiana*, *Ailanthus excelsa*, and *Acacia nilotica*) at Nagaur (Rajasthan). The results indicated that *C. ciliaris* had highest yield (1840 kg ha^{-1}) with *Z. mauritania* followed by with *A. nilotica* (1510 kg ha^{-1}) and *A. excelsa* (1240 kg ha^{-1}). During the fourth year the total fodder yield (dry grass + dry leaf of the tree) was higher (3633 kg ha^{-1}) for *Z. mauritiana* system compared to *A. nilotica* (2931 kg ha^{-1}) and *A. excelsa* (2231 kg ha^{-1}) based silvipastoral systems.

Patidar *et al*., (2008) assessed yields of *Cenchrus ciliaris, Lasiurus sindicus* and cowpea (*Vigna unguiculata* (L.) Walp. sown in strips in association with early stage of *C. mopane* and *H. binata* in hot arid region. They found that green forage yield for sole *C. ciliaris,* sole *L. sindicus*, *C. ciliaris* + cowpea and *L. sindicus* + cowpea systems were 4.59, 4.96, 4.84 and 4.95 Mg ha^{-1}, respectively. The dry fodder yields for the respective systems were 1.65, 1.87, 1.74 and 1.81 Mg ha^{-1}. The differences among these production systems in terms of yields were non-significant. However, the grass + legume strip cropping (*L. sindicus* + cowpea and *C. ciliaris* + cowpea) had significantly higher protein yield (207-215 kg ha^{-1}) than sole grass production (124-138 kg ha^{-1}) systems.

Silvi-pasture system is more profitable compared to rainfed cropping (Shankar, 1995), and other land use systems (Gajja *et al*., 1999) in arid region. Shankarnarayan *et al*. (1987) found that *Acacia tortilis* based silvi-pasture had higher net return (Rs. 3895 ha^{-1}) compared to sole tree (Rs. 3000 ha^{-1}) and grass (Rs. 1150 ha^{-1}) production systems. Economic analysis carried out at ICAR-CSWRI, Avikanagar suggests that silvi-pasture (three, two and single tier systems) land use had higher returns (Rs. 1616.29-2056.3 ha^{-1}) compared to natural pasture (Rs. 922.42 ha^{-1}) (Anonymous, 1998).

***Alley farming and agri-silviculture*:** Growing of trees with agricultural crops is an age old practice in arid and semi-arid regions. *Prosopis cineraria, Holoptelea integrifolia* (Roxb.Planch and *Hardwickia binata*Roxb.are suitable tree species for agri-silviculture system in dryland hot arid region of Rajasthan (Muthana and Arora, 1977; Shankarnarayan *et al*., 1987). The *Z. nummularia, A. tortilis, A. senegal, P. cineraria, C. polygonoides,* and *T. undulata* are the suitable species for the region receiving 50-200 mm annual rainfall. The *P. cineraria, H. binata, C. mopane, Dichrostachys cinerea* (L.) Wight & Arn. (syn. *D. nutans* (Pers.) Benth.), *A. excelsa, G. tenax, A. nilotica,* and *Z. mauritiana* are the suitable species for the region receiving 250-400 mm annual rainfall (Harsh, 1995). Crop production with *P. cineraria* enhanced productivity of drylands crop by 15-20% (Faroda, 1998). A tree density of 100-200 plants ha^{-1} was found to be optimum for minimum interference with yield of dryland crops like clusterbean under *P. cineraria* canopy shade. Besides good yield of dryland crops, bonus yield of dry leaves and twigs (650-1050 kg ha^{-1}) and fuel wood of 1.8-2.6 t ha^{-1} could be obtained from tree through annual lopping (Bhati *et al*., 2008). Kaushik and Kumar (2003) assessed fodder yields in different cropping systems in association with *Prosopis cineraria* (6 m × 5 m) in hot arid rainfed region of Haryana. They found significant higher green and dry fodder yield in association with *P. cineraria*. They reported that cowpea-toria (*Brassica tournefortii*), pearl millet-toria and cluster bean-toria cropping systems had 3.92, 6.22 and 3.09 Mg ha^{-1} higher green and 1.36, 1.81 and 1.13 Mg ha^{-1} higher dry fodder yield compared to sole crop production (crops without *P. cineraria* tree). Economic analysis of these production systems indicated that fodder cropping systems in association with *P. cineraria* were more profitable (net return Rs. 12800-15200 ha^{-1})

compared to sole crop production (net return Rs. 3100-4500 ha^{-1}).

Azadirachta indica A. Juss. and *Ailanthus excelsa* based agri-silviculture systems (involving cowpea, green gram, clusterbean and sesame crops) recorded 59 and 26% higher returns, respectively compared to sole arable cropping in hot arid region of Gujarat (Patel *et al*., 2008). In addition to higher returns these production systems provides multiple products (fodder, fuel wood, timber) and improved soil organic carbon. Besides improving productivity of per unit land the agri-silviculture system improves the soil properties. Tarafdar (2008) reported substantial improvement in soil biological activities under agri-silvi-system (*Prosopis cineraria, Tecomella undulata*, *Ziziphus mauritiana*) compared to sole crop in arid lands.

***Horti-pasture*:** Growing of fruit trees and grasses together i.e. horti-pasture is one of the potential alternate land use systems for providing fruit and fodder for drylands (Singh and Osman, 1995). Sharma and Vashishtha (1985) evaluated ber (*Ziziphus mauritiana*) and *Cenchrus ciliaris* based horti-pastoral system. They found that *C. ciliaris* provided 0.84 Mg ha^{-1} fodder along with good fruit yield. The introduction of *C. ciliaris* in 15 year old ber plantation gave 29 kg $tree^{-1}$ fruit along with 5 Mg ha^{-1} of fodder and 50 kg grass seed ha^{-1} (Vashishtha, 1997). Tewari *et al*. (1999) reported that an improved ber-*C. ciliaris* based horti-pasture system can provide 1.55, 2.64, 1.87, 2.77 Mg dry grass, fuel wood, leaf fodder and fruit respectively. Gajja *et al*., (1999, 2004) reported that horti-pasture system is more profitable than arable crop production in hot arid region.

***Live fences*:** Besides providing protection against wild life and demarcation of farm boundaries, the creation of live fences around household/farms may provide fodder, fuel wood and food. Dwivedi *et al*., (2008) gave detail account of tree and shrubs species suitable for arid region of Rajasthan. The important species having fodder potential suitable for live fencing are: *Acacia jacquemontii, A. senegal, Balanites aegyptiaca* (L.) Del., *Calligonum polygonoides, Capparis decidua, Clerodendrum phlomidis* L.f., *Grewia tenax, Maytenuse marginatus* (Willd.) Ding Houand *Ziziphus nummularia*.

***Fodder bank*:** Fodder bank is intensive feed garden of fodder trees/shrubs, perennial grasses and herbaceous legumes planted at high densities and managed to provide fodder either on a continuous basis or for particular periods such as during dry season. The fodder bank has good relevance to the arid and semi-arid zones where rainfall is adequate to support plant growth for at least two months of the year. Fodder bank can be grazed directly by livestock for a certain period of time to supplement grazing or in used cut and carry system where stock numbers are low. The suitable fodder tree and shrub species in accordance with prevailing rainfall and soil characteristics should be used to create live fodder bank.

Constraints limiting fodder trees and shrub production and utilization:

The significance of trees and shrubs especially for livestock feed have been widely recognized in arid and semi-arid regions. But their potential has not been effectively utilized due to several social, agronomic and technical limitations. Some of most important limitations are as under:

- The paucity of suitable tree and shrub species for cultivation in arid region. Only a few species have been adequately studied for use in existing and improved alternate land use systems suited to arid region.
- Lack of standardization of propagation and management techniques of suitable tree and shrub species for different alternative land use systems.
- Most rangelands of arid region are community owned and thus their lack of proper care and management which often leads to their degradation with misuse and even depletion of tree and shrubs population.
- Incidence of pests, disease and invasive species has become a major concern for effective utilization of browse species.
- Inadequate knowledge pertaining to anti-nutritional substances of most of the browse species limits their effective utilization.

Research and development needs

Species domestication and evaluation for specific land use systems, designing suitable propagation and management techniques, assessing livestock feeding value and social, economic and environmental impact analysis

of these species are important researchable avenues for effective utilization of trees and shrubs in range lands, mixed cropping and pasture in the arid region. The research should focus particularly on the following aspects:

- Collection and evaluation (agro-climatic and production system specific agro-morphological and nutritional evaluation) of germplasm, particularly underutilized and neglected species.
- Developing effective propagation and establishment techniques.
- Designing suitable management techniques i.e. planting density, cutting management (frequency, age at first harvest, intensity, height etc) to optimize productivity in variety of production systems (sole planting, integration with pasture, arable crops).
- Assessing contribution of trees/shrubs to livestock nutrition and production
- Developing suitable models for integration of trees/shrubs in different land use systems.
- Economic evaluation of fodder production and browse supplementation systems over a wide range of conditions and production systems
- Creating awareness about multiple roles (productive and protective) of these species among people of arid region.

Conclusion

Fodder trees and shrubs play an important role in livestock feeding in arid region. These species have excellent physio-morphological adaptations to survive under harsh climatic conditions of hot arid region. Besides providing nutrition to livestock, they impart stability in production, improve soil, ameliorate microclimate for better growth of associate vegetation and check soil degradation. High grazing pressure, inefficient land use policies coupled with frequent and prolonged drought have led to depletion of these species from natural and managed production systems. Silvopastoral, agri-silviculture, horti-pasture, live fence and fodder bank are suitable options to integrate these species into production systems. Their integration besides augmenting fodder availability provides other economic products, improve returns and ensure sustainable use of land and water. However, their use is limited due to paucity of suitable germplasm and inadequate knowledge about cultural, management practices and precise information on economic, social and environmental benefits associated with their uses.

There is urgent need to intensify research and development efforts to domestication and evaluation of germplasm of woody perennial particularly neglected and underutilized species for specific land use systems, designing suitable propagation and management techniques, assessing livestock feeding value and social, economic and environmental impact analysis of these species for effective utilization of trees and shrubs of the arid region.

Abbreviation: ADF: Acid detergent fiber, ALUS: Alternate land use system, CP: Crude protein, CF: Crude fiber, DM: Dry matter, EE: Ether extract, NDF: Natural detergent fiber, NFE: Nitrogen free extract, TCHO: Total carbohydrates.

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